



Refinement of the ISABELE method regarding uncertainty quantification and thermal dynamics modelling

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ABSTRACT

In the construction sector, strong efforts are being made to reduce energy consumption in buildings, particularly regarding thermal insulation in northern countries. However, the objectives set for the thermal insulation performance of the building envelopes are rarely achieved in practice. For this reason, there is increasing interest in taking onsite measurements. This paper presents the new achievements obtained by the ISABELE (In Situ Assessment of the Building Envelope pERformances) method for data treatment to evaluate the global transmission heat transfer coefficient of a building with a consolidated uncertainty and within a short unoccupied period. Most of the work relates to the quantification and propagation of systematic errors and to the adaptation of the thermal model used for the inverse method. Practical applications on a test cell and a demonstration on a low-energy house in real outdoor conditions are presented, as are comparisons with other measurement methods (coheating, Quick U-Value of Buildings (QUB)) and the resulting calculated parameters, which show coherent outcomes. The test cell results reveal that a stabilized, repeatable measure with an acceptable uncertainty range ($\pm 10\%$ in average) can be obtained within 2 days. The house results are slightly less precise ($\pm 15\text{--}20\%$) but can be obtained just as quickly, assuming that both configurations are insulated from the inside.

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1. Introduction

Understanding the discrepancy between calculated and measured energy consumption is a key step to improve the energy performance of new and refurbished buildings. This objective is essential to comply with energy consumption reduction policies related to the issue of climate change. As many factors can contribute to this discrepancy (e.g., occupancy, weather conditions, energy management, intrinsic performance of the envelope and equipment), it is important to provide a quality control strategy of the building lifecycle and to focus on the key stages [1,2]. Previous studies have shown important and systematic discrepancies (from 6 to 140%) between calculated and measured transmission heat transfer coefficients. On average, the size of the gap in percentage terms is 50% [3]. These results refer to 25 coheating tests [4] on residential dwellings and were confirmed by 27 EBBE tests [5,6] on new energy efficient buildings (consisting of non-residential buildings, collective and individual dwellings). A related study of the impact on energy consumption revealed that a 20% increase in the heat transfer rate can lead to a 30% increase in heating consumption

[6]. These gaps can be explained by various factors, such as the following:

- Calculation errors (e.g., neglected thermal bridges).
- Noncompliance of materials (e.g., order errors, supply failures, economic constraints).
- Damage to material performance during shipping and storage (e.g., shock impact, rain damage to thermal insulation).
- Workmanship quality (e.g., manufacturing errors, training gaps, time constraints).

In addition to managing the risks associated with these issues, the need for a final test to accurately characterize the intrinsic thermal performance of the building envelope is important to ensure its compliance. The aim of the ISABELE (In Situ Assessment of the Building Envelope pERformances) method is to provide such a measurement in a relatively short time (several hours to several days), with a rigorous evaluation of the measurement uncertainty that considers the following:

- Test conditions (e.g., building characteristics, weather).
- Time duration.
- All input uncertainties, including conventional hypothesis (e.g., surface heat transfer coefficients, wall solar absorptivity, local sensor positions).

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Nomenclature

A	area, m ²
A_{sw}	solar aperture, m ²
B_0	coheating statistical bias, W
c	specific thermal capacity, J/(kg.K)
C	thermal capacity, J/K
C_L	overall air leakage coefficient of a building, m ³ /(h.Pa ⁿ)
CP	pressure coefficient
DF	degree of freedom
H	thermal transmittance, W/K
HTC	whole-building heat transfer coefficient, including infiltration, W/K
h	surface heat transfer coefficient, W/(m ² .K)
ln	intercept of a linear regression
n	overall leakage exponent of a building
P	heat power, W
$q_{sw, h}$	vertical south global solar radiation, W/m ²
$Q_{Ap, surf}$	permeability of a building for a specific applied pressure of 4Pa, m ³ /(h.m ²)
m	infiltration air flow rate, m ³ std/h
R	thermal resistance, K/W
Sl	slope of a linear regression
T	temperature, °C
t	time, s
u	standard uncertainty
U	enlarged uncertainty (95 % confidence interval)
V	wind speed, m/s
X	explicative variables of a linear regression
Y	explicated variables of a linear regression
α	solar absorptivity
ϵ	model prediction error, K
σ	standard deviation
ω	relative humidity, %
θ	set of fitted parameters

Index

M	bolded variables are matrix variables
$\hat{R}$	estimation of the variable R
$\bar{R}$	average value of the variable R
$Var(R)$	variance of the variable R
$Cov(R, S)$	covariance of the variables R and S

Subscripts

conv	thermal convection
e	outdoor air
em	ISABELE equivalent outdoor node or thermal resistance for heavyweight envelope components
e,eq	equivalent outdoor air (infiltrated)
es	ISABELE equivalent outdoor node or thermal resistance for lightweight envelope components
h	heating device
i	indoor air
init	initial
is	ISABELE model relation between indoor air and star nodes
inf	infiltration
l	thermal mass of lightweight envelope components
leew	leeward side of a building
m	thermal mass of heavyweight envelope components
mi	thermal mass inside a building
obs	observation
pl,black	black plate of a sensor

pl,white	white plate of a sensor
pred	prediction
rand	random or repeatability-related error
rad	thermal radiation
roof	roofing
star	inner equivalent ambience
syst	systematic or rightness-related error
tot	total (in the context of external walls)
tr	transmission
w	water
wall	outer walls
wind	windward side of a building

Indeed, such considerations are not considered by similar methods in the literature but are crucial to obtain an accurate assessed value. This paper presents two important contributions for the ISABELE method, namely, the adaptation of the dynamic thermal model and a more rigorous uncertainty calculation. First, a brief overview of the latest developments and the previous version of the ISABELE method are given (more information can be found in the references). Then, the results of practical applications on full-scale experimental configurations in real outdoor conditions are provided to validate the updated version.

2. State of the art

2.1. Brief review

Methods developed to measure the intrinsic thermal performance of the building envelope from data measurements have been studied both in the PERFORMER project [www.performerproject.eu] and in the IEA EBC Annex 58 project on reliable building energy performance characterization based on full scale dynamic measurements [7]. These methods can be classified into two categories:

- Methods applicable when the building is in use, i.e., with occupancy.
- Methods only applicable when the building is empty for a certain amount of time, i.e., with no occupancy.

Methods with occupancy need as much data as possible in cold periods; therefore, several cold seasons of study are recommended. The first concept is based on an energy signature and consists of performing a simple energy balance, plotting, for example, energy consumption as a function of the temperature difference between the inside and outside environments and calculating a global heat transfer coefficient for this analysis. This concept (implemented, for example, in the PRISM method [8]), can measure the efficiency of a deep refurbishment, but may be challenging to determine the contribution of the envelope alone from the global gain (including the energy system efficiency, hot water consumption, and user behaviour, for example). Other methods of parameter identification based on dynamic measurements have been used to identify suitable models to describe the thermal characteristics of a building (including its energy systems), by using lumped parameter RC models [9–11]. This approach can be useful to predict the dynamic behaviour of buildings for optimizing energy grids for building communities and to roughly estimate the global heat transfer coefficient but is not appropriate for physical quantity estimation. Other methods, such as EBBE [5], are based on a thermal model and consist of calibrating the envelope performance described in this model by incorporating both measurements and occupant behaviour information based on inquiries. The main challenge with the methods that are applied when the building is in use involves

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